

# Empowering Decentralized Microgrids with A Blockchain-Based Peer-To-Peer Energy Trading Platform

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## Abstract

This study explores the concept of a Peer-to-Peer Energy Trading Platform for Decentralized Microgrids through Blockchain Technology. The presented work focuses on the creation of a decentralized peer-to-peer energy trading platform using blockchain technology, which is designed for microgrid ecosystems. The study delves into blockchain's ability to build trust and ensure the integrity of energy transactions. The study concludes with recommendations for future enhancements, including expanding platform capabilities, integrating diverse energy sources, and navigating regulatory challenges for widespread adoption and impactful change.

*Keywords:* Peer-to-Peer (P2P), Blockchain Technology, Energy Trading, Decentralized Microgrids

## 1. Introduction

Adopting blockchain technology as a P2P energy trading platform can offer a decentralized, distributed digital ledger that securely records transactions among prosumers in an energy marketplace. It ensures transparency, immutability, and trust without relying on a centralized authority, making it an ideal technology for managing energy trading in microgrid society [1]. The potential usage of blockchain technology can help facilitate and create a P2P energy trading platform. Besides, a blockchain system can record all transactions that are maintained across computers [2].

Cryptocurrencies like Bitcoin have been used for Double-spending as effective digital assets between the prosumers in the P2P energy trading platform. Practically, the transaction inputs (sender's address, energy consumer), transaction output (recipient's address, energy producer), and the amount of cryptocurrency involved in the energy trading process are the three main components of each block on the Bitcoin blockchain [3]. Ethereum blockchain is open-source, which is a worldwide platform that enables users to store data precisely and monitor digital assets via smart contracts. Every activity on the network requires a certain quantity of computational power, or "gas". Gas limits are the most

permitted units of gas for a specific operation, and they are determined and enforced by Ethereum's blockchain for every operation. The main purpose of the Ethereum blockchain is to support decentralized applications [3], [4].

By expanding on the Transactive Energy Management System, peer-to-peer energy trading can be carried out more easily and without the need for a middleman. Through the DApp, each user registers on the system and provides the details needed to engage in energy trading. The Transactive Energy Blockchain (TEBCN) smart contract records this data in the blockchain system together with the amount of energy to purchase or sell and the price per megawatt-hour. The DApp system asks the back-end server for a response. By taking this action, the back-end server is prompted to enable communication between agents to guarantee the transfer of the designated quantity of energy. The energy seller receives the energy cost expressed in ethers once the back-end server confirms the energy transfer [5], [6], [7].

Niloy F.A. et al. [8] brought up the idea of a network between peers where the participants pose as clients or even as servers with the ability to share their assets safely. Energy trading in the smart grid can be accomplished more effectively by utilizing a P2P network in blockchain technology. This P2P energy trading platform enables the

prosumers to their need for kWh from the closest source directly. Furthermore, in this case, users of P2P energy sharing will utilize blockchain-based smart contracts, which are autonomous. Like this, these blockchain-endorsed smart contracts will process and store the records of each transaction that occurs within the system through the Advanced Metering Infrastructure (AMI) [9].

Most conventional energy trading is a one-way strategy. Large-scale generators usually send their electricity over great distances to end-users. Commonly, two or more middlemen exist between the energy producers and consumers to complete the energy trading cycle. In this case, the end-users are paying not only for middlemen but also for power transmission. This increases the energy unit price multiple times. Therefore, buying the energy directly between peers and reducing the cost of transmission could significantly reduce the energy unit price. For instance, the Reserve Bank of Australia reported that only 45% is the energy unit's whole sale price meanwhile the rest 55% is divided into retail operation costs by 10% and network costs by 45% [10]. Therefore, buying the energy directly between peers and reducing the cost of transmission could significantly reduce the energy unit price. The P2P energy trading could also promote decentralized trading within a local geographic area. Accordingly, new market strategies are needed to determine pricing, decentralize the energy market, and control the energy infrastructure considering the rise in renewable energy use at the domestic level. Establishing such a market could enable prosumers to transact directly on renewable energy generation without the need for middlemen, which would be granting a much fairer price in buying a selling energy unit. It was reported that P2P energy trading in microgrids could improve the local balance between energy generation and consumption caused by the diversity of the produced energy resources [11].

As shown from the literature, P2P energy trading can be categorized into centralized, distributed, and decentralized markets. Research in the previous works focused on improving scalability, reliability, privacy, and autonomy in centralized markets, designing proper pricing mechanisms, modelling decision-making processes in distributed markets, and utilizing blockchain technology for decentralized platforms.

The novelty of this work lies in the innovative application of blockchain technology to create a decentralized P2P energy trading platform tailored for microgrids. Unlike traditional energy systems, this platform enables direct energy transactions between users without the need for intermediaries, ensuring greater economic efficiency, transparency, and security. The integration of IoT sensors for real-time monitoring, combined with the future use of smart contracts within the IBM Hyperledger Fabric framework, represents a significant advancement in automating and securing energy trades. This study uniquely addresses the practical challenges of implementing blockchain in energy trading, such as ensuring data accuracy, managing user

interactions, and maintaining system performance under varying conditions.

## 2. Methodology

This subsection integrates principles from blockchain selection, system architecture design, smart contract development, and decentralized microgrid integration into a structured process. An efficient and secure energy trading platform has been established. It mainly aims to serve community-driven energy exchanges, promote sustainability, and enhance the resilience of decentralized energy infrastructures. Adopting blockchain solutions in a P2P energy trading platform in a decentralized microgrid structure will completely change how prosumers deal with their excess renewable energy resources. Practically, the prosumers have complete control over the amount of energy that they want to buy or sell amongst other prosumers. For instance, the client has the choice to trade the energy quantity and source, renewable or not, in the same microgrid and national grid.

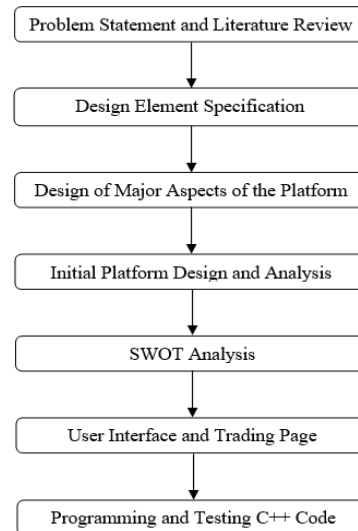


Fig. 1 Methodology Flow Chart.

Figure 1 demonstrates a flowchart for the conducted methodology which starts with determining the problem statement supported by a relevant literature review. Subsequently, design modelling would be executed then software/program selection and finalising. The next step comprises validation and analysis of the proposed design to be tested to ensure its viability and safety. Finally, the manufacturing and testing stages would be performed. During this stage, the design product would be created to demonstrate its capability and a better visual representation.

### 2.1. Blockchain Selection

Ethereum blockchain was primarily developed for the exploitation and support of decentralised applications. Using the Ethereum blockchain allows for trading and dealing with tokens for energy transactions. Besides, Ethereum allows for maintaining digital ledger transactions, where all the trading activities performed

using any web interface are recorded with timestamps. It also allows the designing of smart contracts, which authorizes the creation of real-time contracts in the energy market. Additionally, the Ethereum blockchain can be used for distribution application deployment and testing in a deterministic and secure environment. Furthermore, the Ethereum blockchain can be linked and integrated with an external key software such as MetaMask which is necessary to complete this work. These selected features, including the Ethereum blockchain, ultimately enable the P2P energy trading fairly and securely.

## 2.2. System Architecture Design

The Transactive Energy Blockchain (TEBCN) platform integrates three primary frameworks: the Multi-Agent System (MAS), the Ethereum blockchain, and the Distributed Application (DApp). This architecture facilitates secure and efficient decentralized energy exchanges. The Ethereum blockchain records energy costs and transaction amounts, enhancing transparency and reliability. Smart meters installed at each prosumer's location provide accurate energy usage data, supporting the MAS in simulating energy flows. The MAS framework, implemented using the Java Agent Development Framework (JADE) and the FIPA-Agent Communication Language (ACL), manages agent interactions and transaction processing. The MAVEN software platform integrates MAS with the blockchain network and DApp, ensuring centralized project management. Each participant is assigned an Ethereum blockchain address, with smart contracts compiled and deployed using the Truffle development environment and simulated on the Ganache blockchain emulator. MetaMask, a cryptocurrency wallet, allows users to monitor their accounts and execute transactions. Overall, this system architecture ensures secure recording of data changes and smart contract executions on the blockchain, providing a robust platform for decentralized energy trading.

## 2.3. Decentralized Microgrid Integration

In the decentralized microgrid, each prosumer controls their energy exchange, enhanced by blockchain technologies for heightened security. This integration ensures a balance between energy generation and consumption, reducing the wastage of renewable energy sources. In the cases of excess or insufficient energy, mutual trading within the utility network enables energy balance among microgrid users. This decentralized, or smart microgrid environment, ensures uninterrupted power trading and acts as an aggregator to manage power routing. Prosumers and microgrids can collaborate to improve services and reduce electricity costs, adapting to changing environments during extreme events to ensure efficient energy trading. This cooperation makes electricity prices more affordable and promotes profitable trading of transactive energy nodes. Every house in the

microgrid is equipped with a smart meter to analyze power usage and predict surplus or deficit states. Consumers can decide how much power to purchase or sell within the microgrid. Once stabilized, separate microgrids can connect for broader possibilities, enhancing the decentralized energy trading system.

## 3. Results and Discussions

### 3.1. Installation of IoT Measuring Sensor

The first step in setting up the whole system would be to gain access to the power generated by the solar panels and the house's power consumption. This is vital in determining whether that specific house has a positive excess power value or a negative one. This is an essential parameter because the house user is only able to trade the excess power with other users. Moreover, installing an IoT sensor that can monitor and track the power generation and consumption values in actual time is important to ensure a seamless connection between the excess power values and the other users who are using the platform. For this purpose, a Sense Home Energy Monitor is used as an IoT sensor. This IoT sensor can monitor continuously the flow of electricity through the main electric panel of the house. Practically, it can determine how much energy is generated by the solar system of the house, as well as how much is the total energy consumption of that house. The data that is tracked by this IoT sensor will send the live data to its cloud server. We will then take this live data from the Sense cloud server and duplicate these values onto our platform's server. This is to ensure that the actual power excess value and the excess power value on the platform are the same. This works perfectly to sync the real-time data with the data displayed on the platform.

### 3.2. User Account Set Up

Once the Sense IoT sensor is installed and synced up, the account will be set for the users on the platform. These users will be given a unique Account Identification (ACC ID) username and password. Each house will only be able to make a single account. This is also done to ensure both the safety and security of the user, other users, and the entire platform. If required, we can also provide the service of briefing the user on how to navigate and use the platform. When the account is set up, the power excess value of the house will be displayed on the platform once the user logs into the platform. The users can also check their account information, check their excess energy value, buy or sell their excess energy, and check their transaction history, as shown in [Figure 2](#).

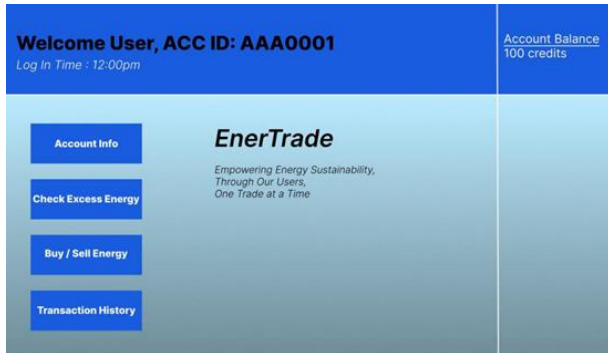


Fig. 2 Sample of the User Interface after Logging In.

### 3.3. Converting Excess Power to Platform Currency

When each user has their platform account set up, they can begin trading excess power on the platform. However, to continue with this step, the users need to convert their access energy into the blockchain currency via Ethereum Blockchain. One easy way to conduct this consists of two steps. The first is to convert the excess power from the houses into Malaysian Ringgit. This is done by calculating the value of the excess power according to the Domestic Tariff (Tariff A) that is set by TNB. Once the excess power is calculated in the Malaysian Ringgit value, we can convert the value of the excess power in Malaysian Ringgit to the currency used on the application, Ethereum, via Ethereum Blockchain. Once the platform has converted the value of the user’s excess power from Malaysian Ringgit to Ethereum Blockchain, the currency will be updated in the user’s account. Finally, the user can trade, which is either buying or selling their excess power on the platform, as shown in Figure 3.

TARIFF CATEGORY	UNIT	CURRENT RATE
<b>Tariff A - Domestic Tariff</b>		
For the first 200 kWh (1 - 200 kWh) per month	sen/kWh	21.80
For the next 100 kWh (201 - 300 kWh) per month	sen/kWh	33.40
For the next 300 kWh (301 - 600 kWh) per month	sen/kWh	51.40
For the next 300 kWh (601 - 900 kWh) per month	sen/kWh	54.40
For the next kWh (901 kWh onwards) per month	sen/kWh	57.10
The minimum monthly charge is RM3.00		

Fig. 3 Tariff category according to the domestic tariff.

### 3.4. Fully Functioning User Account on the Platform

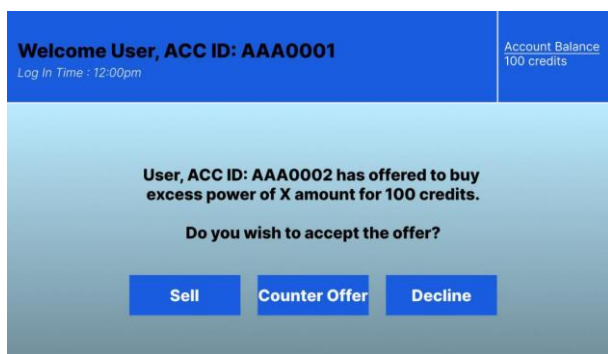


Fig. 4 Screen shot for a sample of a Trade between two platform users

Figure 4 demonstrates that once the user's accounts are completed, they have the choice to buy or sell their energy through the platform. In the proposed platform, the user with the ACC ID of AAA0002 is offering to buy

“X” amount of excess energy from another peer with the ACC ID of AAA0001 for 100 Credits. Besides, user AAA0002 requires this amount of excess energy for their house’s usage, thus the AAA0001 can offer to buy the excess energy from user AAA0001 for 100 credits. In this case, the user AAA0001 has the option to either sell his excess home-generated energy for 100 credits, counteroffer for a better price or decline the offer. If the user AAA0001 chooses to accept the offer, the 100 credits from user AAA0002 will be transferred to the app first as a third party. Once the user AAA0002 receives the requested energy, the 100 credits will be released to the user AAA0001. This procedure could prevent any unreasonable refunds that can be requested because Ethereum performs a one-way transaction. This is because a refund scenario could make the P2P energy trading process complicated or even inapplicable.

### 3.5. C++ Coding Results

Figures 5-9 display the C++ programming code while it in operation. These figures also demonstrate the C++ programming code outcomes while it in operation.

```
Output
/tmp/RVcp8pI2LI.o
AAA0002 offers to buy 100 units of power from AAA0001 for 100 credits.
AAA0001, you have received an offer from AAA0002 to buy 100 units of power for 100 credits.
Do you want to [S]ell, [C]ounter offer, or [D]ecline? |
```

Fig. 5 Initial outcome of the code prior to selecting an option.

```
Output
/tmp/w94QZL8mr7.o
AAA0002 offers to buy 100 units of power from AAA0001 for 100 credits.
AAA0001, you have received an offer from AAA0002 to buy 100 units of power for 100 credits.
Do you want to [S]ell, [C]ounter offer, or [D]ecline? S
Transaction Successful!

=== Code Execution Successful ===
```

Fig. 6 Outcome after Selecting the ‘Sell’ option.

```
Output
/tmp/CNsUmGnVzR.o
AAA0002 offers to buy 100 units of power from AAA0001 for 100 credits.
AAA0001, you have received an offer from AAA0002 to buy 100 units of power for 100 credits.
Do you want to [S]ell, [C]ounter offer, or [D]ecline? C
Enter your counter offer price: 120 credits
AAA0002 accepts the Counter Offer!

=== Code Execution Successful ===
```

Fig. 7 The successful outcome after selecting the ‘Counter Offer’ option.

```
Output
/tmp/oBSKD561J4.o
AAA0002 offers to buy 100 units of power from AAA0001 for 100 credits.
AAA0001, you have received an offer from AAA0002 to buy 100 units of power for 100 credits.
Do you want to [S]ell, [C]ounter offer, or [D]ecline? D
Transaction Failed!

=== Code Execution Successful ===
```

Fig. 8 The Outcome after Selecting the ‘Decline’ option.

```

Output
Clear

/tmp/1imMcDhoP5.o
AAA0002 offers to buy 100 units of power from AAA0001 for 100 credits.
AAA0001, you have received an offer from AAA0002 to buy 100 units of power for 100
credits.
Do you want to [S]ell, [C]ounter offer, or [D]ecline? C
Enter your counter offer price: 200 credits
AAA0002 declines the Counter Offer!

=== Code Execution Successful ===

```

Fig. 9 The unsuccessful outcome after selecting the 'counter offer' option.

#### 4. Conclusion

A blockchain-based peer-to-peer (P2P) energy trading platform for decentralized microgrids was developed and implemented to ensure a secure, transparent, and efficient energy transaction. The platform's design, which includes the integration of IoT sensors and the use of IBM Hyperledger Fabric for smart contracts, facilitated real-time monitoring and automated trading processes. This approach could address key challenges such as economic efficiency, data accuracy, and transaction security. Additionally, the developed platform is capable of converting excess energy into Ethereum for trading effectively demonstrating a novel method for energy monetization. Moreover, reduced transaction costs, increased renewable energy usage, and enhanced consumer empowerment validated the platform's practical application and its potential to revolutionize energy trading are another major outcome of this study.

Nevertheless, several constraints were encountered during the development and implementation of the blockchain-based peer-to-peer (P2P) energy trading platform for decentralized microgrids. Scalability of the blockchain network, while effective for small-scale deployments, may face challenges in handling a larger number of transactions and users simultaneously. Additionally, the reliance on IoT sensors for real-time data collection introduced potential vulnerabilities related to data accuracy and sensor malfunctions, which could affect the reliability of energy transactions. The integration of Ethereum for energy trading, although innovative, posed challenges in terms of regulatory compliance and market acceptance, as the cryptocurrency market is still subject to significant volatility and legal scrutiny.

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#### Authors Introduction

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